

# **Stratified Flow, Wave Packet Reflection and Topographic Currents**

George F. Carnevale  
Scripps Institution of Oceanography 0213  
9500 Gilman Drive  
La Jolla, CA 92093-0213  
phone: (858) 534-4775 fax: (858) 534-8045 email: [gcarnevale@ucsd.edu](mailto:gcarnevale@ucsd.edu)

Award #: N00014-97-1-0095

## **LONG-TERM GOAL**

Our basic aim is to achieve a better understanding of the turbulent flow of the oceans in terms of the laws that govern the behavior of vortices and waves and their interactions.

## **OBJECTIVES**

In our internal-wave project, we are using numerical simulations to study the dynamical evolution of internal wave packets. The observations of Alford and Pinkel (2000) show that overturning in the thermocline is often associated with the passage of an internal wave packet. We hope to model numerically and theoretically the evolution of such packets and their interaction with the ambient field. We also plan to study in detail the process of reflection of a packet from regions of weak density gradient. Packets propagating away from the thermocline may be reflected back toward the thermocline. In the process of reflection, high amplitude packets may break causing mixing. This would tend to erode the boundaries of the thermocline.

In our project on coastal interactions, the questions that we are trying to answer have to do with how the presence of a coast affects the basic processes involved in the evolution of vortices and currents. We wish to understand the role that bottom topography plays in permitting or inhibiting the bifurcations of coastal currents. We are investigating the role of topography in establishing the circulation in the Adriatic. In particular we want to understand the circulation above the Jabuka or Pomo and South Adriatic Pits.

## **APPROACH**

These investigations involve analytical and numerical studies. In our internal-wave investigations, we are performing simulations with both spectral and finite-difference three-dimensional simulation codes with subgrid scale models. We use an idealized wave-packet as an initial condition. The range of scales in these problems is so large that we need to resort to subgrid parameterizations to render the computations feasible.

In our coastal current investigations, we are comparing the results from barotropic quasi-geostrophic model simulations for specific processes with results from a 41 layer model of flow in the Adriatic. To answer basic questions about the relative importance of fluctuations in wind forcing and

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>30 SEP 2001</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2001 to 00-00-2001</b>	
4. TITLE AND SUBTITLE <b>Stratified Flow, Wave Packet Reflection and Topographic Currents</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Scripps Institution of Oceanography 0213,,9500 Gilman Drive,,La Jolla,,CA, 92093</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <b>Our basic aim is to achieve a better understanding of the turbulent flow of the oceans in terms of the laws that govern the behavior of vortices and waves and their interactions.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>6</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

topographic effects, we are embarking on a series of simulations in which not only the winds, but also the topography will be modified.

## **WORK COMPLETED**

For our stratified flow work, we have completed preliminary studies on both the continually forced flow at the 20 m vertical scale and the propagation of a wavepacket of the type described above. This work is detailed in Carnevale, Briscolini and Orlandi (2001), Carnevale and Orlandi (2000) and Carnevale, Briscolini, Orlandi and Kloosterziel (2001). To better understand the mixing resulting from the breaking of internal waves, we have investigated the Rayleigh-Taylor instability. An article on this has been submitted to JFM (Carnevale, Orlandi, Zhou and Kloosterziel, 2001). For our flow over topography studies, we have used the DieCast model to simulate the flow in the Adriatic. With this model, we have begun a series of comparison runs with different winds to achieve the topographic flows that we wish to study. Also, in connection with our earlier quasi-geostrophic models, a question arose about the validity of various boundary conditions, and we have investigated this further in the context of oceanic circulation. This study is reported in Carnevale, Cavallini and Crisciani (2001).

## **RESULTS**

We examined the propagation of a low amplitude packet trying to exit the thermocline. We found that such a packet can be reflected from a region of weak stratification without losing coherence, although dispersion causes significant broadening of the packet (see figure 1.). Breaking of strong packets on reflection will erode the density gradient further. We have performed two and three dimensional simulations to investigate these matters. Through three-dimensional simulations, we have demonstrated that rotation can suppress the formation of the turbulent mixing zone (TMZ) that results from the Rayleigh-Taylor instability (see figure 2.), and we have analyzed this result in terms of the vortex ring structure within the bubbles that drive the development of the TMZ.

Our recent work on the Adriatic simulation has concentrated mainly on creating a stand alone model of the circulation that is valid for many year runs. Preliminary tests have revealed unexpected difficulties with prescribing the boundary conditions, and a variety of solutions are now being attempted.

## **IMPACT/APPLICATION**

It is often rather difficult to reconstruct the flow structures in a given volume of ocean from available observational data. Various explanations may be offered to explain a particular overturning event seen in a density profile. By simulating flows that produce similar structures in a three dimensional data set, we hope to be able to decide on the validity of various hypotheses that may be used to explain the occurrence of such structures. We have found strong mixing events in regions of high strain and steep isopycnal slope, and these may be related to the overturning events observed by Alford and Pinkel (2000). We shall study how these events can be triggered by the passage of a strong wavepacket as suggested by Alford and Pinkel. Our results on the Rayleigh-Taylor instability may help us better understand mixing resulting from overturning of internal waves.

Our results on coastal current bifurcations may be useful in analyzing the flow in a variety of places where strong topographic variations occur in the along-shore direction. In particular, the flow along the steep side of the Jabuka pit in the Adriatic seems to be a good example of the flow we can predict analytically. We have compared the trajectories of drifter tracks (Poullain, 1997) and found that many

line up with the steep gradient of the northwestern edge of the pit indicating a current, very much as our results predicted.

## **RELATED PROJECTS**

In addition to our work discussed above, we completed a study on the effect of thermal perturbation on trailing vortices behind aircraft (Orlandi, Carnevale, Lele and Shariff, 2000). We are also collaborating with R. Kloosterziel (U. Hawaii) on the stability of vortices in stratified flow and on internal wave packet propagation.

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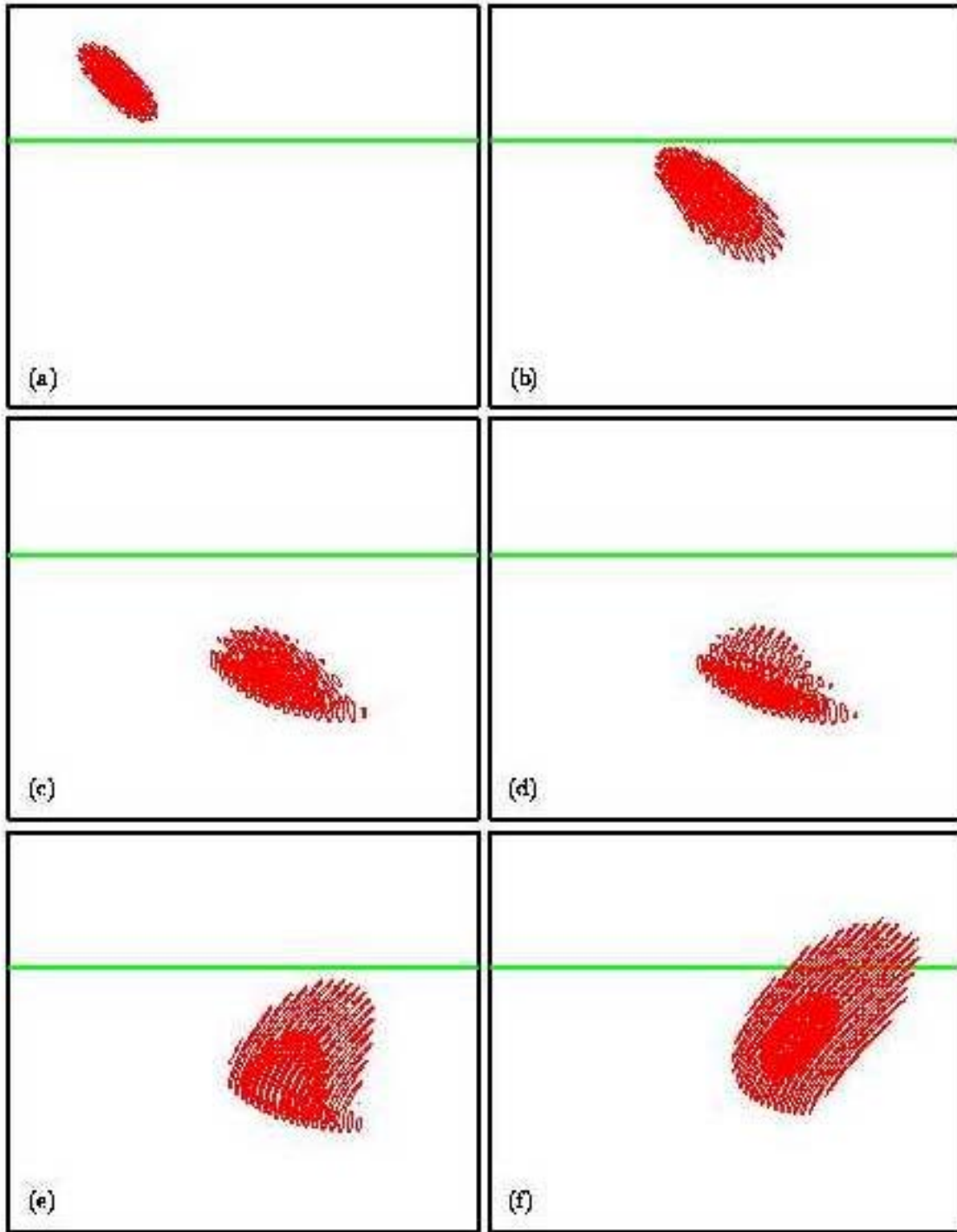
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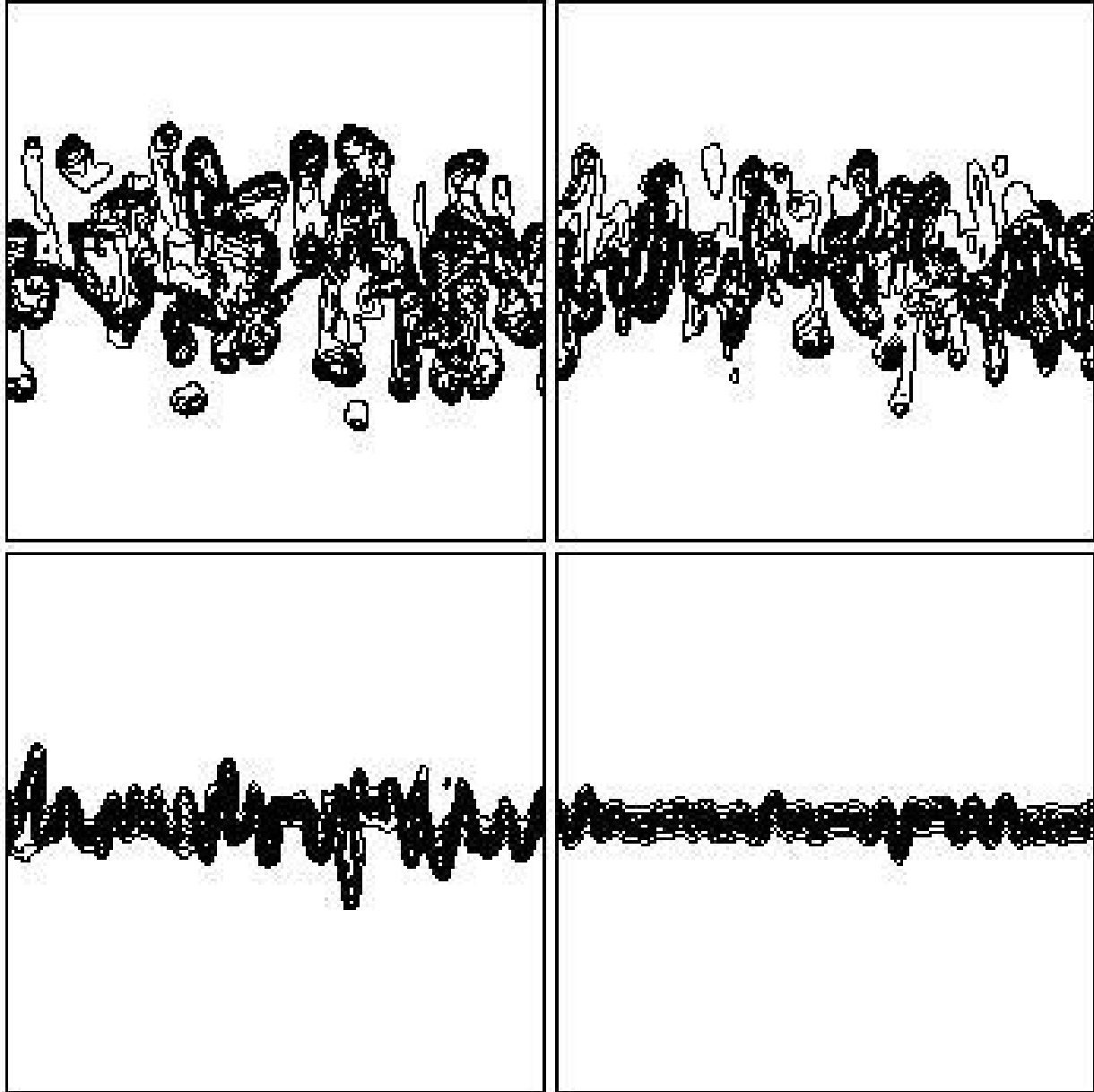
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*Figure 1. Contours of perturbation density showing propagation of an internal wave packet. The area shown is a vertical cross section meant to model the lower portion of the thermocline. The mean unperturbed density in this model has a constant Brunt-Vaisala frequency  $N$  above the green line. Below this line, the frequency decreases with depth. The packet propagates from the high  $N$  region downward into the region of decreasing  $N$ . On reaching a depth at which the frequency of the packet is greater than  $N$ , the packet is reflected and begins to move upward back to the region of higher  $N$ .*



*Figure 2. Contour plots of the density field at time  $t=5$ , for four different Rossby numbers ( $Ro = \infty$ ,  $1/4$ ,  $1/8$ ,  $1/12$  from left to right, top to bottom). For the two higher Rossby numbers, a turbulent mixing zone has been established by time  $t=5$ . For the larger Rossby numbers, the growth of the mixing zone has been greatly retarded. The density varies from a low value at the bottom to a high value at the top of each figure with the contour level increment being one tenth of the difference.*